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DISCRIMINATION TECHNIQUES FOR REGIONAL EVENTS AT NORSAR USING A SINGLE SITE

Philip R. Laun, et al

Texas Instruments, Incorporated

Prepared for:

Advanced Research Projects Agency
Air Force Technical Applications Center

31 December 1974

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TECHNICAL REPORT NO. 10

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

Prepared by
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Prepared for

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Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
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The purpose of this study was to determine the best discrimination technique for shallow earthquakes and presumed explosions occurring in the NORSAR first zone ($150 \leq \Delta \leq 2000$ km). Single-site instrument-corrected NORSAR short-period data was used for the analysis. The three discriminants investigated were: depth, phase energy ratios, and spectral splitting. The depth discriminant requires more accurate epicenter locations for the

20. Continued

smaller events than is presently the case. The phase energy ratios appear to be an effective discriminant, but the spectral splitting discriminant needs a broader range of magnitudes before it can be evaluated.

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ABSTRACT

The purpose of this study was to determine the best discrimination technique for shallow earthquakes and presumed explosions occurring in the NORSAR first zone ($150 \leq \Delta \leq 2000$ km). Single-site instrument-corrected NORSAR short-period data was used for the analysis. The three discriminants investigated were: depth, phase energy ratios, and spectral splitting. The depth discriminant requires more accurate epicenter locations for the smaller events than is presently the case. The phase energy ratios appear to be an effective discriminant, but the spectral splitting discriminant needs a broader range of magnitudes before it can be evaluated.

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SECTION I

INTRODUCTION

In the past several years teleseismic signals from Eurasian events have been studied extensively using data from seismic arrays around the world. Sophisticated signal enhancement techniques have been developed to lower the thresholds for detecting and discriminating small magnitude events. However, many low magnitude events which occur within the Eurasian continent remain undetected simply because their signals are so weak at teleseismic distances that present processing techniques cannot extract them from the noise.

Thus it is desirable to have detection and discrimination techniques which are tailored to data from non-teleseismic events so that these events can be used to lower the detection and discrimination thresholds.

The purpose of this study was to determine the parameters best suited for distinguishing between shallow earthquakes and presumed underground explosions occurring in Eurasia at less than teleseismic distances from the observer. These discrimination parameters will be used for small magnitude Eurasian events detected at small distances (most likely by only one station). Clearly, lowering the discrimination threshold, requires smaller distances just for event detection. Further, these near source seismograms contain most of the information required for crustal studies.

In this study we are mainly concerned with the distance range at which the primary wave (first arrival) is refracted horizontally below the Mohorovicic discontinuity (Pn). The distance range at which the Pn is the first arrival has been found by Pasechnik (1970) to be $\Delta \leq 800$ to 1200 km.

which he terms 'first-zone'. For the range of $1200 \leq \Delta \leq 2000$ km. he terms the second zone. Carder (1952), on the other hand, uses the term near-regional for $150 \leq \Delta \leq 650$ km. and regional for $650 \leq \Delta \leq 1600$ km. We use the terms first zone and regional interchangeably throughout this report but meaning distances within the general range of $150 \leq \Delta \leq 2000$ km.

First-zone studies in Eurasia have been principally reported by Pasechnik (1970). He observed that both earthquakes and explosions from the same region have the same phases and travel-times but that the dynamic characteristics of the phases were different. His first-zone information is concerned mainly with travel-times and phase identification.

First-zone studies from the Nevada Test Site, on the other hand, are quite extensive. Because the epicenter locations and times were well known, and a large data base was available for both earthquakes and explosions, the results of these studies have been used here to delineate the first-zone problem areas and to decide on the more effective discrimination measurements. Some of the first-zone problems of interest are the following:

- The first-zone seismograms are quite complex because of the presence of many wave phases. These phases have only small differences in theirtravel times.
- First-zone seismograms are highly dependent on local crustal structure and thus the amplitude and travel-time curves are variable.
- Magnitude measurements in the first-zone have not been as reliable or consistent as the corresponding teleseismic estimates.

Three discriminants that appeared most promising for single station first-zone discrimination were:

- Depth estimation - Use of possible depth phase travel-times.

- Phase energy and amplitude ratios - Explosions will presumably generate less shear or surface wave energy than earthquakes.

- Spectral splitting - Source spectrum studies suggest spectral differences between earthquakes and explosions of equivalent magnitudes.

An accurate assessment of these discriminants requires that broad-band data covering the spectrum of the event be used. The most convenient source providing data of this type was the NORSAR array. For this report, NORSAR data from a single short-period site and a corresponding nearby long-period site was used.

This report is arranged in the following manner: Section II deals with the data base, Section III with processing and analysis, and Section IV contains the pertinent conclusions and suggestions for future work.

SECTION II

DATA

The NORSAR array at Kjeller, Norway was chosen as the source of first-zone data for a number of reasons. First, the array is situated close to areas where presumed explosions have occurred. The propagation path for these signals is continental and the crustal properties in Scandinavia have been studied in detail. As for the array itself, both high quality vertical component short-period data and three component long-period digital data are produced. The NORSAR Data Processing Center (NDPC) also publishes a bulletin of events detected by the array. This bulletin reports many low magnitude regional events which do not appear in the PDE bulletin.

These NORSAR data are obtained in two different ways. The short-period data are ordered from the Norwegian Data Processing Center at Kjellar, Norway and mailed to the Seismic Data Analysis Center (SDAC). Thus an approximate, three month time lag exists between the data request and having the short-period data on hand to process. All long-period data are transmitted in real time via a trans-Atlantic communications link to the SDAC and recorded there on magnetic tape. So these data were available immediately. However, uncorrectable parity errors on the long-period data tapes resulted in having only three events with usable long-period data. Other events with usable short-period and long-period data could not be received in time to include in this report. No long-period data results are presented in this report due to the small amount of long-period data.

A first-zone or regional event list was compiled from both the PDE bulletin and the NORSAR bulletin for the period from June 1973 through October 1973. The earthquakes were restricted to this time period due to the previously mentioned ordering time and a six months data retention limit at NORSAR. Two earlier presumed explosions in September of 1971 and 1972 were available, however, and were included. Table II-1 lists these ten earthquakes and ten presumed explosions with their associated epicenter parameters. Figure II-1 shows the location of these events relative to NORSAR.

The accuracy of the event parameter information in Table II-1 varies considerably between the source bulletins. The NOAA-PDE information is usually quite reliable since many stations are used to determine epicentral parameters and m_b values. The events listed on the NORSAR bulletin can have location errors up to 160 km. and differ in m_b value from the single instrument in the array of up to 2.2 m_b units. These deviations are due to event location by a single array station (NORSAR) and inaccurate regional m_b estimates due to NORSAR regional beamforming problems (Ringdal and Whitelaw, 1973). The consequences of these problems in the NORSAR bulletin are discussed in the following sections.

TABLE II-1

EVENT LIST AND PARAMETERS

	Designation	Date	Origin Time	Lat.	Long.	Depth	m_b	Source
1.	WES/262/11N	9-19-71	11:00:06.8	57.8N	41.1E	0.0	4.5	P *
2.	KOL/248/07N	9-04-72	07:00:03.6	67.7N	33.4E	7.0	4.6	P
3.	FIN*156*06S	6-05-73	06:29:35.0	61.0N	24.0E	0.0	3.1	N
4.	WRS*166*12N	6-15-73	12:52:01.0	58.0N	42.0E	33.0	3.2	N
5.	WRS*180*155	6-29-73	15:54:54.0	61.0N	29.0E	0.0	3.5	N
6.	FIN/188/10S	7-07-73	10:51:25.0	60.0N	29.0E	0.0	3.4	N
7.	WRS*222*12N	8-10-73	12:54:00.0	61.0N	29.0E	33.0	3.3	N
8.	WRS*227*14S	8-15-73	14:08:35.0	60.0N	29.0E	0.0	3.5	N
9.	NVZ/255/06N	9-12-73	06:59:54.3	73.3N	55.2E	0.0	6.8	P *
10.	NVZ/270/06N	9-27-73	06:59:58.0	70.8N	53.9E	0.0	6.0	P *
11.	WRS*270*13S	9-27-73	13:10:53.0	60.0N	29.0E	0.0	3.5	N
12.	WRS/273/04N	9-30-73	04:59:57.5	51.6N	54.6E	0.0	5.2	P *
13.	NOR*276*12N	10-03-73	12:06:40.0	70.0N	31.0E	33.0	3.3	N
14.	FIN*281*12N	10-08-73	12:45:10.0	60.0N	29.0E	33.0	3.3	N
15.	NOR*293*14N	10-20-73	14:21:37.0	70.0N	31.0E	33.0	3.2	N
16.	URA/299/05N	10-26-73	05:59:57.6	53.7N	55.4E	0.0	4.8	P *
17.	NVZ/300/06N	10-27-73	06:59:57.4	70.8N	54.2E	0.0	6.9	P *
18.	NVZ/300/08N	10-27-73	08:03:56.3	70.8N	53.2E	0.0	4.2	P *
19.	NVZ/300/0831	10-27-73	08:21:20.7	70.9N	52.9E	0.0	4.4	P *
20.	NVZ/300/09N	10-27-73	09:13:51.3	71.3N	51.9E	0.0	4.8	P *

Abbreviations:

* = Presumed explosions
P = NOAA-PDE Bulletin
N = NORSAR Bulletin

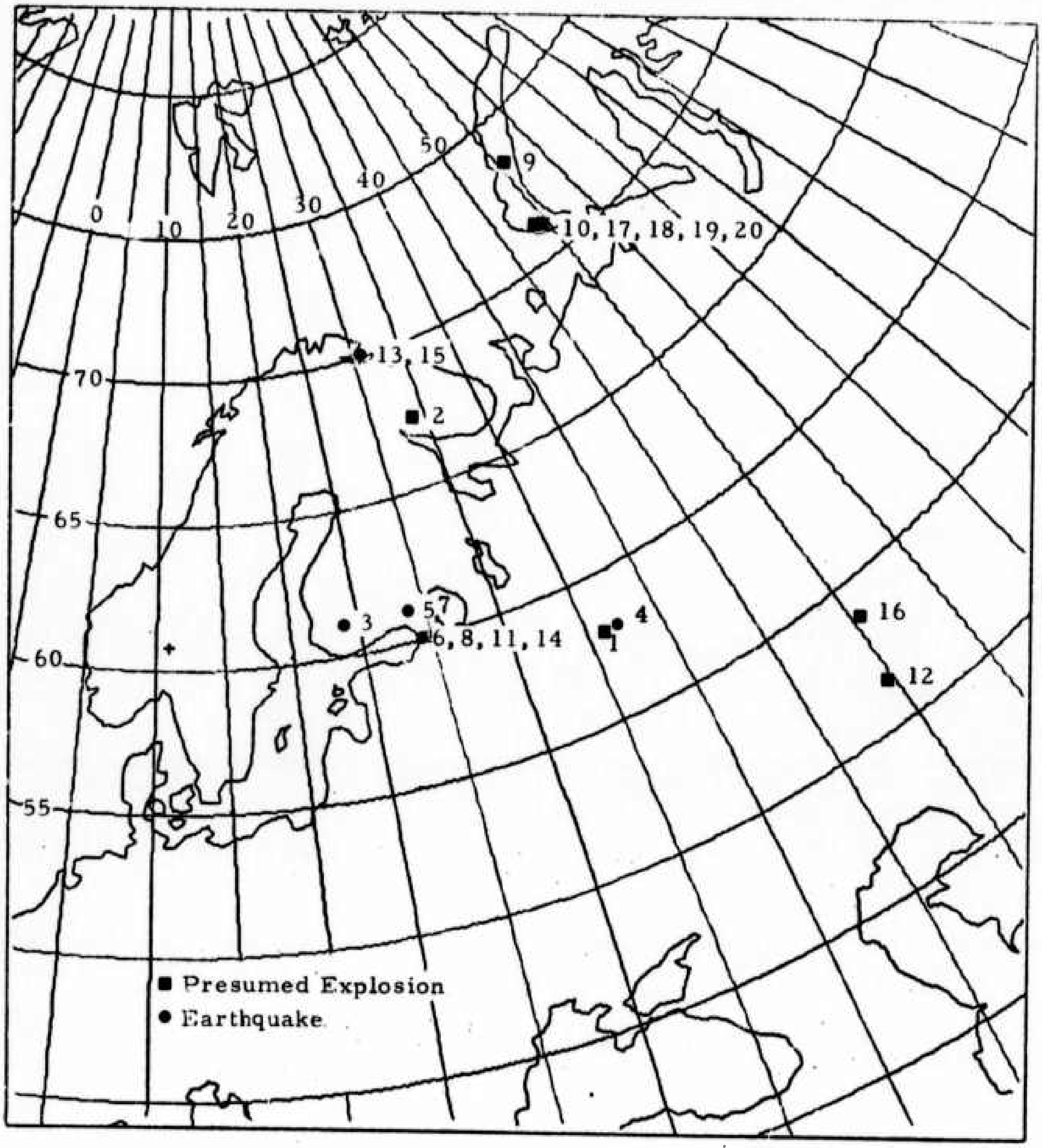


FIGURE II-1

EVENT LOCATION BY EVENT NUMBER

SECTION III

PROCESSING AND ANALYSIS

A. PROCESSING

The raw NORSAR short-period data first were edited from the library tapes from Norway. The edit procedure reformats the single sensor time series, performs simple quality checks, and transfers the data to a working tape. Because the edit program can handle a maximum of 192 seconds of data at a sample rate of 10 Hz, two edits of 192 seconds were run on each event. The first started about twenty seconds before the expected P arrival while the second edit adjoined the first so that 384.0 seconds of contiguous data for each event was edited. Limiting our data samples to 384.0 seconds resulted in the loss of some of the later phases of the more distant events. These distant events were included in our data ensemble to determine the distance at which the first arrival is the teleseismic P-wave rather than the Pn.

After editing, the data from the center sensor of the 22 subarrays were plotted to check the noise characteristics of each subarray and to determine which subarray had the best signal-to-noise ratio (SNR). The data generally was dominated by two-second period noise so a high-pass filter, 0.9 to 5.0 Hz, was applied to remove it and a second filter was applied to correct for instrument response. Figure III-1 is a plot of the instrument response of the short-period system at NORSAR. With one exception, the center sensor from subarray 4 was used for all subsequent analysis because

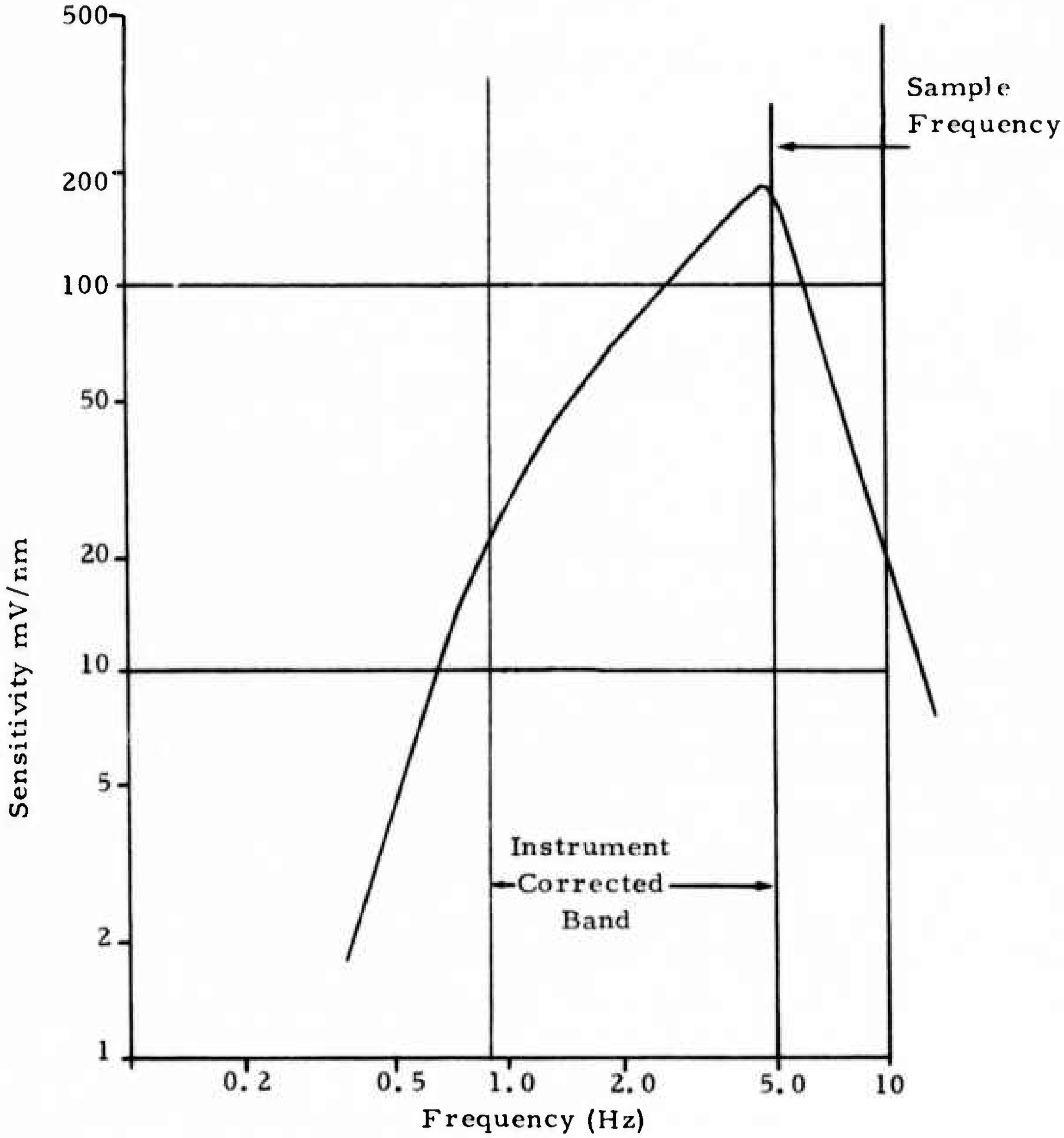


FIGURE III-1

INSTRUMENT RESPONSE, SHORT-PERIOD SYSTEM, NORSAR for most of the events it had the largest SNR. For event 14, FIN*281*12 N, the center sensor from subarray 14 was used because subarray 4 was inoperative. The locations of the NORSAR subarrays are shown in Figure III-2.

Spectral splitting and phase energy ratio determinations were made using the Seismoprint technique (Cohen, 1969). This technique displays the power of a seismic signal as a function of time and frequency. The technique operates by computing successive power spectra from a set of overlapping time gates in the data. The spectral power in each gate is normalized relative to the highest power in the entire set and then displays the resulting spectra using two-dimensional printer plots with power coded by letters. Figures III-3 and III-4 show examples of this output and the letter scales.

In addition, the Seismoprint computes the total power in each time gate to use in the phase energy ratio discriminant. All Seismoprint processing used a 32 point time gate (3.2 seconds) and a time shift of 8 points (75% overlap) which was considered optimum by Cohen (1969).

B. ANALYSIS

1. Phase Travel Time Curves

The P wave and S wave phases were chosen from a plot of all the subarray sensors, so the continuity of the phase across the subarray could be seen. This prevents picking spurious phases on a single sensor. The first arriving P wave was generally visible on these seismograms, but the S wave was more difficult to identify since horizontal instruments were not available for determining shear motion with certainty.

Plots of the P wave and S wave arrival times using the published epicenter times are shown in Figures III-5 and III-6 respectively. Also, plotted on these figures are the Herrin (1968) travel-time curves for P at zero depth (Figure III-5) and the Jeffrey-Bullen (JB)(1940) travel-time

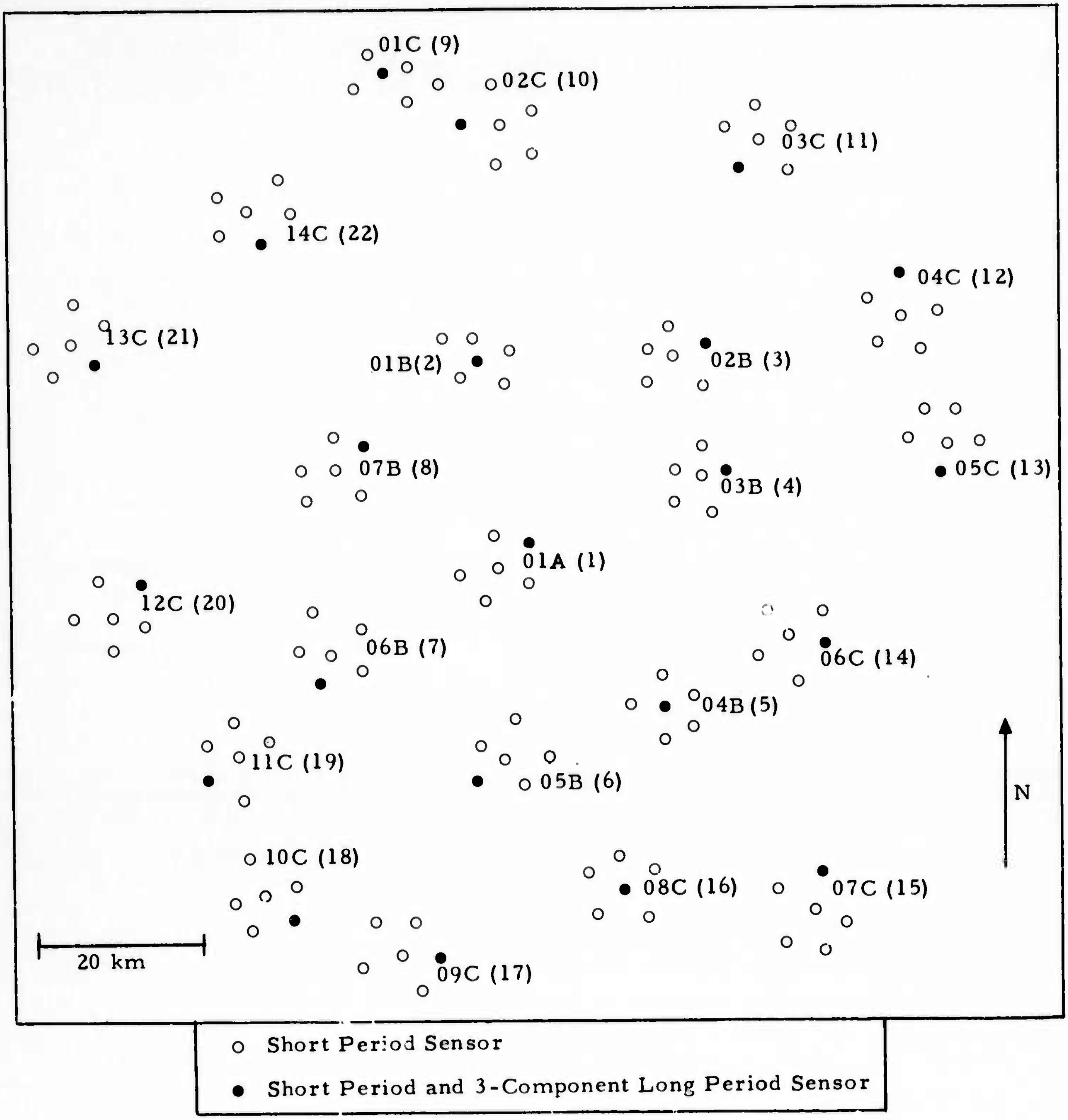
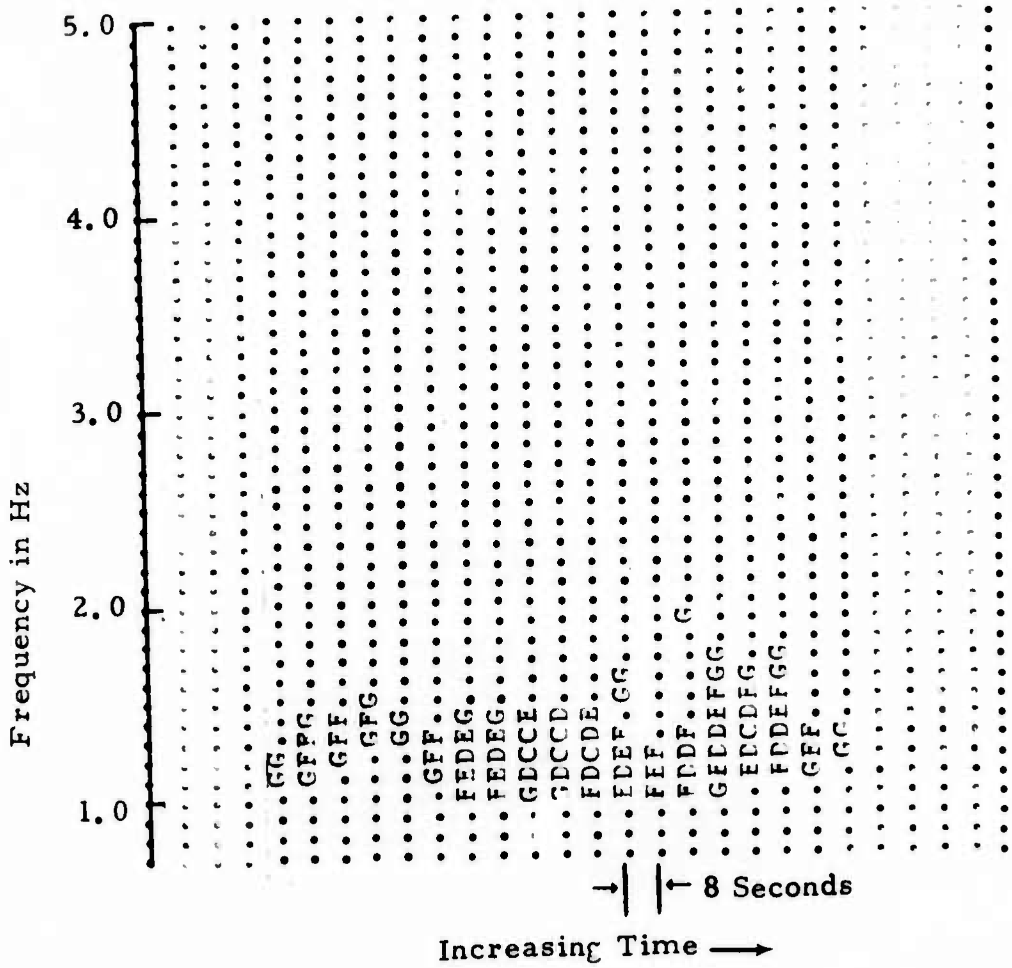


FIGURE III-2

NORSAR ARRAY LOCATIONS



Power Scale

* =	Maximum	D	-6 to -8 dB
A =	0 to -2 dB	E =	-8 to -10 dB
B =	-2 to -4 dB	F =	-10 to -12 dB
C =	-4 to -6 dB	G =	-12 to -14 dB

• = < -14 dB

FIGURE III-3

SEISMOPRINT OUTPUT OF FIRST ARRIVAL P AT NORSAR SINGLE SITE FOR EVENT WRS*166*12N

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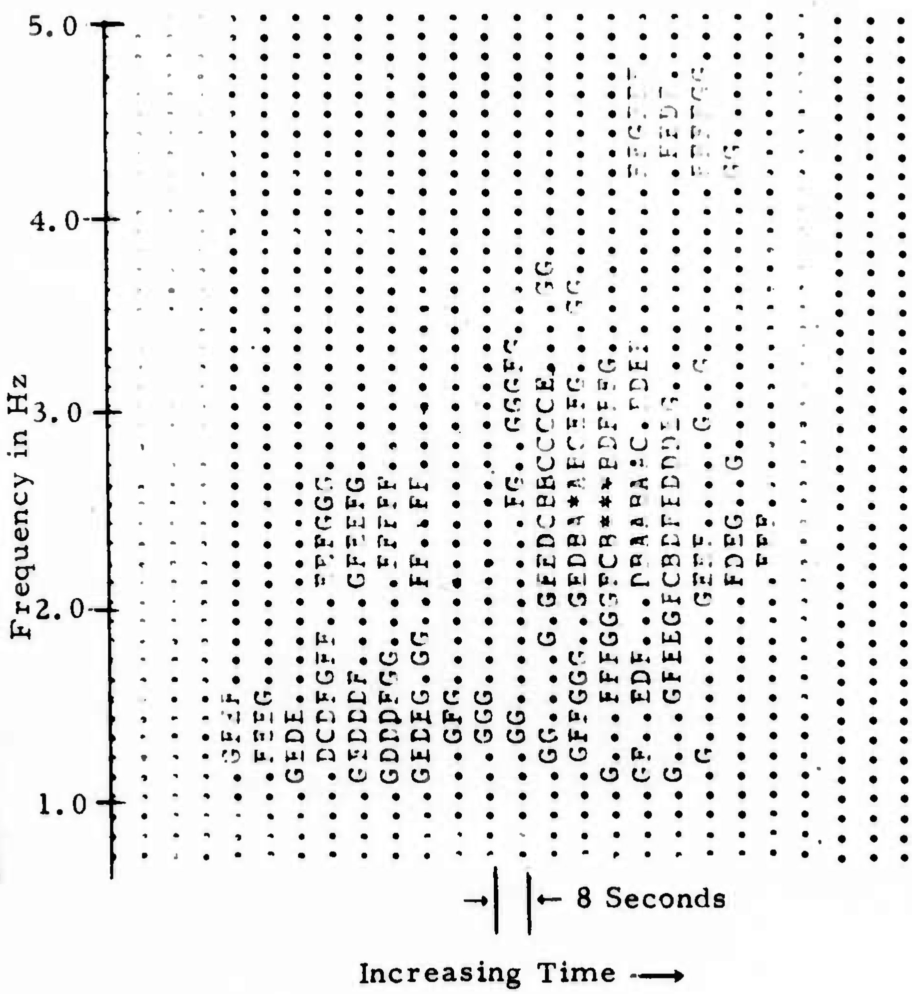

Power Scale

* =	Maximum	D =	-6 to -8 dB
A =	0 to -2 dB	E =	-8 to -10 dB
B =	-2 to -4 dB	F =	-10 to -12 dB
C =	-4 to -6 dB	G =	-12 to -14 dB

• = < -14 dB

FIGURE III-4

SEISMOPRINT OUTPUT OF FIRST ARRIVAL P AT NORSAR SINGLE SITE FOR EVENT WES/262/11N

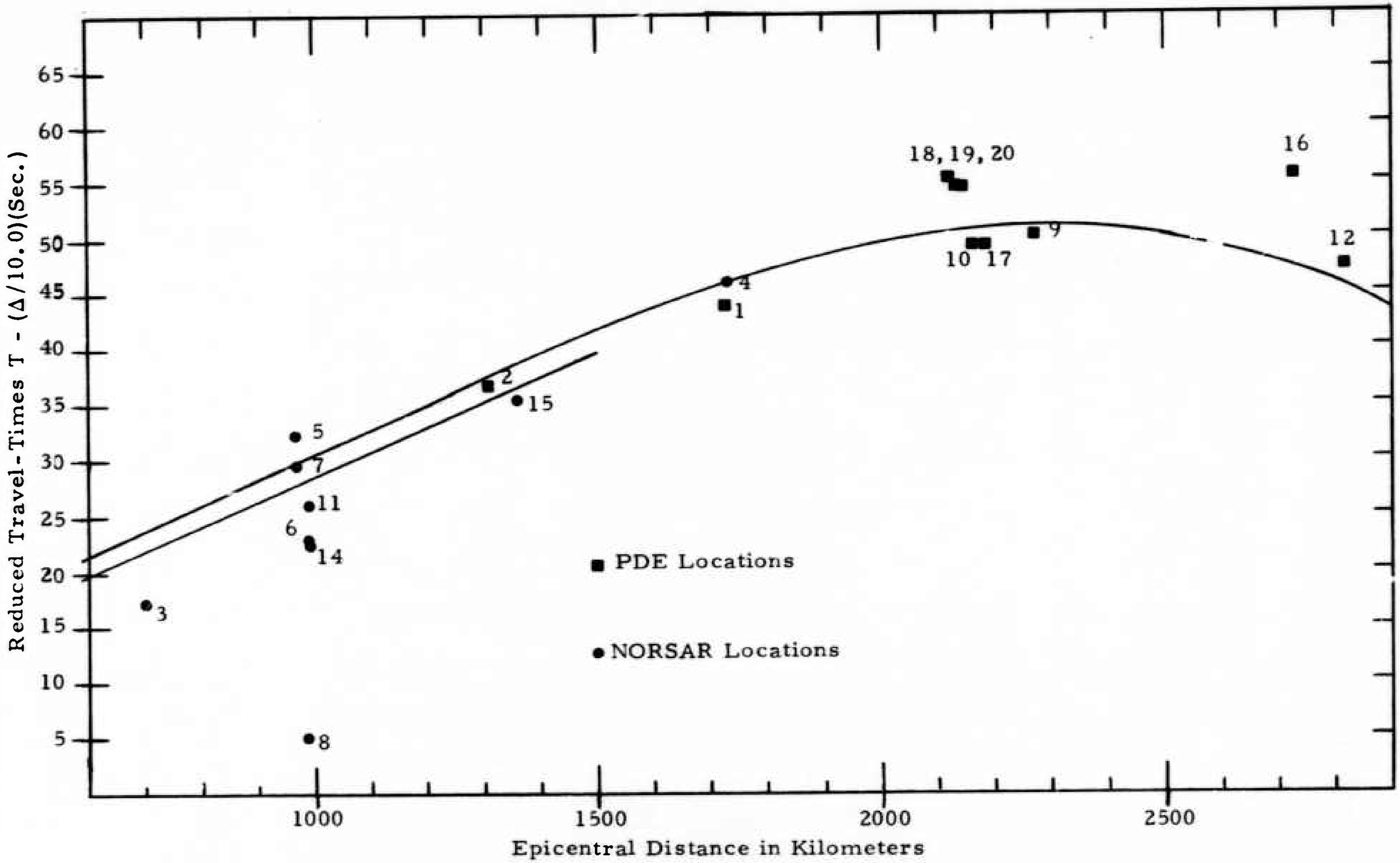

FIGURE III-5

TRAVEL-TIMES OF P-WAVES FOR REGIONAL EVENTS AT NORSAR

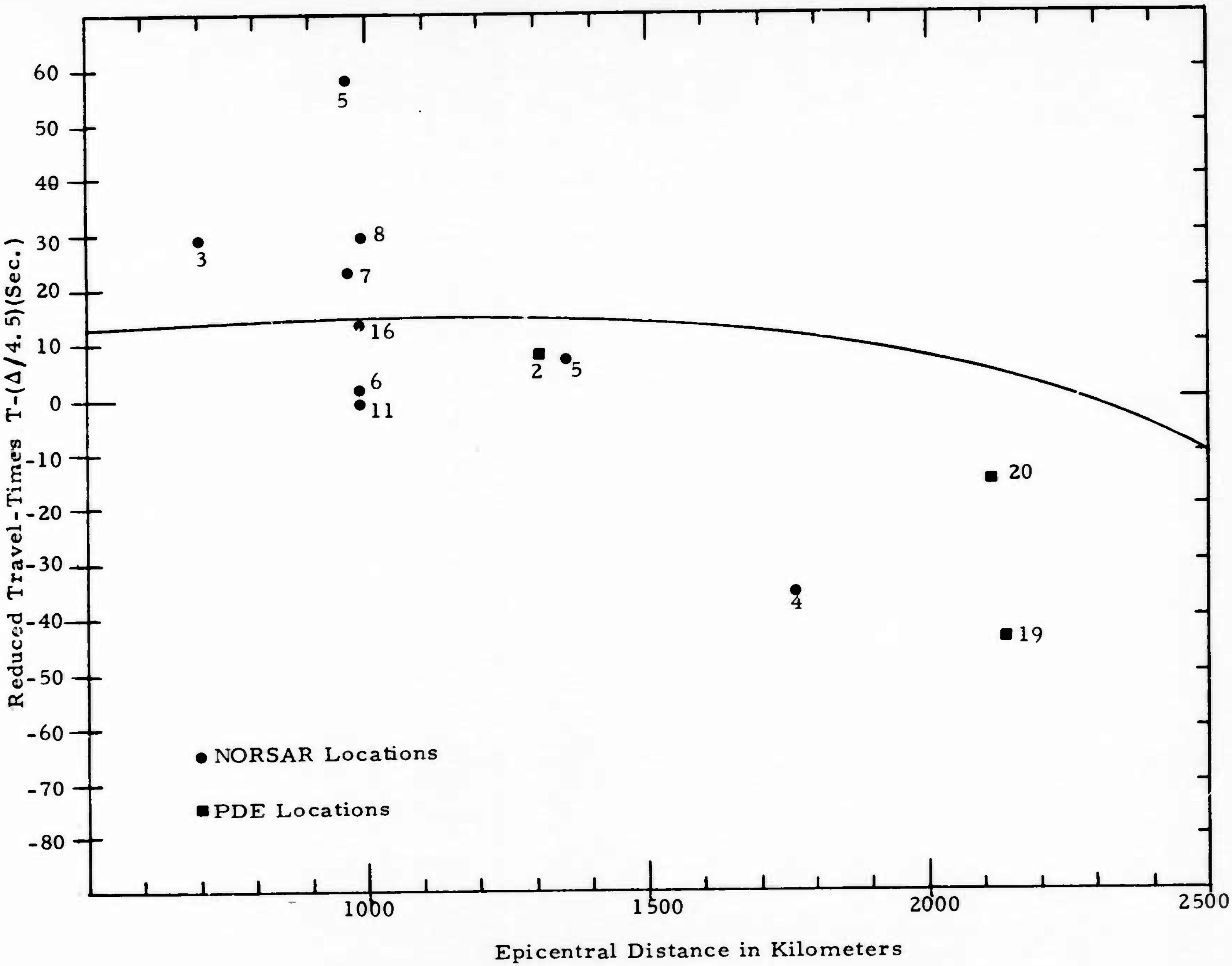

FIGURE III-6

TRAVEL-TIMES FOR S-WAVES FOR REGIONAL EVENTS AT NORSAR curves for S at zero depth (Figure III-6). Note that these times are plotted as reduced travel-times: $T - \frac{\Delta}{10.0}$ for P and $T - \frac{\Delta}{4.5}$ for S.

The NORSAR single site arrival times are independent of the PDE bulletin parameters but are not independent of the NORSAR bulletin parameters. The NORSAR bulletin locations are made from a P wave array beam (F. Ringdal personal communication). The event azimuth is determined by the highest power beam and the event origin time and distance are made from the S minus P arrival times measured on the P wave array beam (that is, the beam time shifted to correspond to the P wave velocity). The single-site P wave and S wave picks should be the same phases as those on the beam. Any differences would be due to the analyst's judgment, or an error in measurement.

The P wave arrival time used to locate the event for the NORSAR bulletin is listed in the bulletin for each event. The independently-picked single-site P arrival time has been compared to this time and is within four records of the array beam time so the same P phases are being used. The exception is event 8 (Table II-1) which has a 20 second difference and appears to be an error in the NORSAR bulletin.

The S wave arrival times are not listed in the NORSAR bulletin but can be infered from the travel-times and epicentral distances. The picking of the S phase is the biggest difference between the array beam and the single site. If the same phase had been used for the array beam and the single site, the arrival times on Figure III-6 would fall on or near the J B curve on Figure III-6.

All of the NOAA-PDE located events with the exception of events 16, 18, 19 and 20 (see Table II-1) fall on or within two seconds of the Herrin (1968) curve on Figure III-5. This two second difference could be an epicenter error of about 20 kilometers or a velocity error of 0.01 km./sec. both of which are within the accuracy of the published error ellipse.

Event 16 (Table II-1) has been located by PDE using 46 stations from many azimuths so that the large variance from the Herrin (1968) curve is probably the result of picking a later phase on the single site. The NORSAR bulletin lists an earlier P arrival time at that array which corresponds closely to the expected P time for this event, but no such phase was visible on any of the single site seismograms.

Events 17, 18, 19 and 20 (Table II-1) are all from the same geophysical area. Event 17 was located by the PDE bulletin using 221 stations from a wide azimuth, whereas the others used from 9 to 18 stations concentrated at azimuths from 40° to 360°. Event 17 has good location control while the rest do not. In addition, most of the stations, including NORSAR, used to locate events 18, 19 and 20 had the highest residual error in event 17 location. This residual error was as large as 6 seconds between the time of the expected P and the actual P. Thus, the arrival times of the events 18, 19 and 20 relative to the Herrin (1968) travel-times in Figure III-5 are probably due to epicenter location errors. These location errors seriously affect most of the first zone measurements, all of which are dependent in some manner on accurate locations and, derived from those, accurate travel-time errors.

2. Estimation of Regional m_b

The general inconsistency between the regional m_b estimate and the teleseismic estimate for the same event is well known. NOAA-PDE m_b values computed using stations at $\Delta < 20^o$ were routinely recomputed omitting these close-in stations.

Because some discriminants are expected to be a function of the magnitude (for example m_b versus M_s), a lack of consistency in the m_b values does affect the value of these discriminants. Thus, an important part of the first-zone study is to obtain reliable regional m_b values which are consistent with the corresponding teleseismic m_b's. Table III-1 lists the event m_b measurements determined in this study from a simple instrument at NORSAR and those reported by the NOAA-PDE and NORSAR bulletins for the same event. The differences between the NORSAR bulletin and the single instrument m_b values (averaging about 0.46 m_b units) are indicative of the beamforming losses in the NORSAR beams for regional events. The m_b values for the single instrument are probably more realistic; however, the single instrument m_b values are often considerably lower than those appearing in the NOAA-PDE bulletin.

Evernden (1967) has successfully corrected the high regional m_b values observed for the NTS events to correspond to the teleseismic m_b measurements. The study by Evernden (1967) requires accurate regional travel-times because each phase is separately normalized to the teleseismic m_b measurement. Upon accumulation of many reliable travel-times in the first zone, a similar type correction will be made for this region.

TABLE III-1

MAGNITUDE MEASUREMENTS FROM THREE SOURCES

Event Number	NOAA-PDE m_b **	NORSAR Beam m_b	NORSAR Single-Site m_b
1 *	4.5	ND	4.31
2	4.6	ND	4.43
3	-	3.1	4.05
4	-	3.2	4.21
5	-	3.5	3.88
6	-	3.4	3.90
7	-	3.3	3.93
8	-	3.5	3.75
9 *	6.8	ND	6.50
10 *	6.0	ND	5.59
11	-	3.5	3.90
12 *	5.2	ND	5.19
13	-	3.3	ND
14	-	3.3	3.78
15	-	3.2	4.11
16 *	4.8	4.9	5.29
17 *	6.9	ND	5.45
18 *	4.2	3.4	3.46
19 *	4.4	3.1	3.40
20 *	4.8	3.8	3.82

** Recomputed using teleseismic m_b values only

* Presumed explosion

ND Not Detected

- No value given

3. Discrimination

The three discriminants investigated in this report are depth, phase energy ratio and spectral splitting. Although the data base is small, a preliminary trial of these discriminants assists in evaluating the various analysis techniques.

a. Depth

The classical depth determinators are the depth phases such as pP and the S minus P travel-time differences. The depth phases are most effective when used in conjunction with other stations because, for example, the pP minus P travel-time difference should remain virtually constant for a given event independent of epicentral distance. The use of the S minus P time does not give a unique answer with the use of one station for event location. That is, the event must be independently located in time and space so the relatively earlier arrival times for deep events can be utilized.

Ten events with phases visible near the expected S arrival time were used to compute S minus P times. These differences were compared to the Jeffrey-Bullen (1940) predicted time differences for zero depth and 33 km. depth. Table III-2 shows the results of this comparison using the one or two phases from near the S arrival time. As seen in Table III-2 only events KOL/248/07N (event 2) and NOR*293*14N(event 15) give results close to those expected. The reason for these variances is due to both location error and differences in S wave arrival time picks discussed in Subsection III-A.

TABLE III-2

S-P TRAVEL TIME DEPTH DETERMINATION

			Observed			J-B 1940			
Event Number	Source	Δ^o	Pn or P T - T	S T - T	S - P Sec	0 Depth S - P Sec	33 Depth S - P Sec	Depth Given	Depth Computed (km)
2	P	11.75	167.2	298.2	131.0	133.0	131.0	7	33
2	P	11.75	167.2	368.9	201.7			7	
3	N	6.30	87.6	184.7	97.1	72.6	71.7	0	
3	N	6.30	87.6	258.0	170.4			0	
4	N	15.86	222.2	356.2	134.0	177.7	164.6	33	>33
5	N	8.71	129.1	273.2	144.1	100.1	97.1	0	
6	N	8.89	125.8	221.4	95.6	102.2	100.2	0	>33
6	N	8.89	125.8	268.8	143.0			0	
7	N	8.71	126.5	238.7	112.2	100.1	97.6	33	
7	N	8.71	126.5	264.8	138.3			33	
8	N	8.89	109.0	249.3	140.3	102.4	100.1	0	
11	N	8.89	124.8	219.2	94.4	102.4	100.1	0	>33
11	N	8.89	124.8	268.2	161.4			0	
14	N	8.86	120.7	231.7	111.0	101.7	99.7	33	
14	N	8.86	120.7	261.8	141.1			33	
15	N	12.21	170.9	308.5	137.6	138.1	136.0	33	<33
15	N	12.21	170.9	390.5	219.6			33	

P = NOAA-PDE
N = NORSAR SP

b. Phase Energy Ratios

Since earthquakes are generally the result of some sort of faulting and explosions are a compressional source, it is expected that earthquake signals will contain more shear and surface wave energy than the explosion signals. The phase energy ratio discriminant is designed to exploit this difference.

As discussed earlier, many of the individual phases were not well identified. That being the case, the comparison of amplitudes and averages between phases might be misleading so this initial study concentrated on gross differences between the two sources similar to that by Booker and Mitrinovas (1964).

For this initial investigation, the short-period seismogram was divided into three broad time frames to take advantage of the assumed differences in earthquakes and explosions. These three time frames contain predominately compressional wave energy, shear wave energy and surface wave energy respectively and are based on the approximate measured travel-time using the following velocity ranges:

P	8.6 km./sec. to 5.0 km./sec.
S	5.0 km./sec. to 4.0 km./sec.
Rg	4.0 km./sec. to 3.0 km./sec.

The total power in each spectrum computed by the seismoprint program was summed over the times corresponding to these velocity ranges, and the ratios between them were computed. Because the short-period record was limited to 384 seconds, the complete Lg phase for $\Delta > 15^{o}$ was not available and the complete S phase for $\Delta > 20^{o}$ was also not available.

At first glance the separation in Figure III-7 appears excellent. In fact, near $\Delta = 15.5^{\circ}$, a presumed explosion and an earthquake occurred within one degree of one another and they are separated in P/S ratio of aboutone order of magnitude. It also appears that the P/S ratio is a function of Δ for the earthquakes and perhaps a different function exists for the presumed explosions. Nevertheless, serious questions can be raised about the validity of this discriminant without further data to support it. For example:

- The P wave amplitude variation (and thus the energy variation) versus distance is well known generally (Archambeau, et al, 1969); however, the S wave amplitude or, in this particular case, the vertical component of S is not well documented. An assumption of a constant Poisson's ratio and an effectively equal attenuation for P and S phases, would make a P/S ratio constant with Δ but it appears not to be the case for these data. Thus, the expected curves are not known.

- It is not known how the magnitude of the event will affect its position on the P/S coordinate, because at the lower magnitudes the noise level energy will be an important portion of the total energy. Obviously, for low SNR events the P/S ratio should be equal to the ratio of the velocity window lengths (in this case; 1.7) but at what SNR the P/S ratio becomes distorted by noise is not presently known.

Regional earthquake measurements are strongly affected by station-source crustal structure more so than are teleseismic measurements, so that phase arrival times and amplitudes may be strongly dependent on

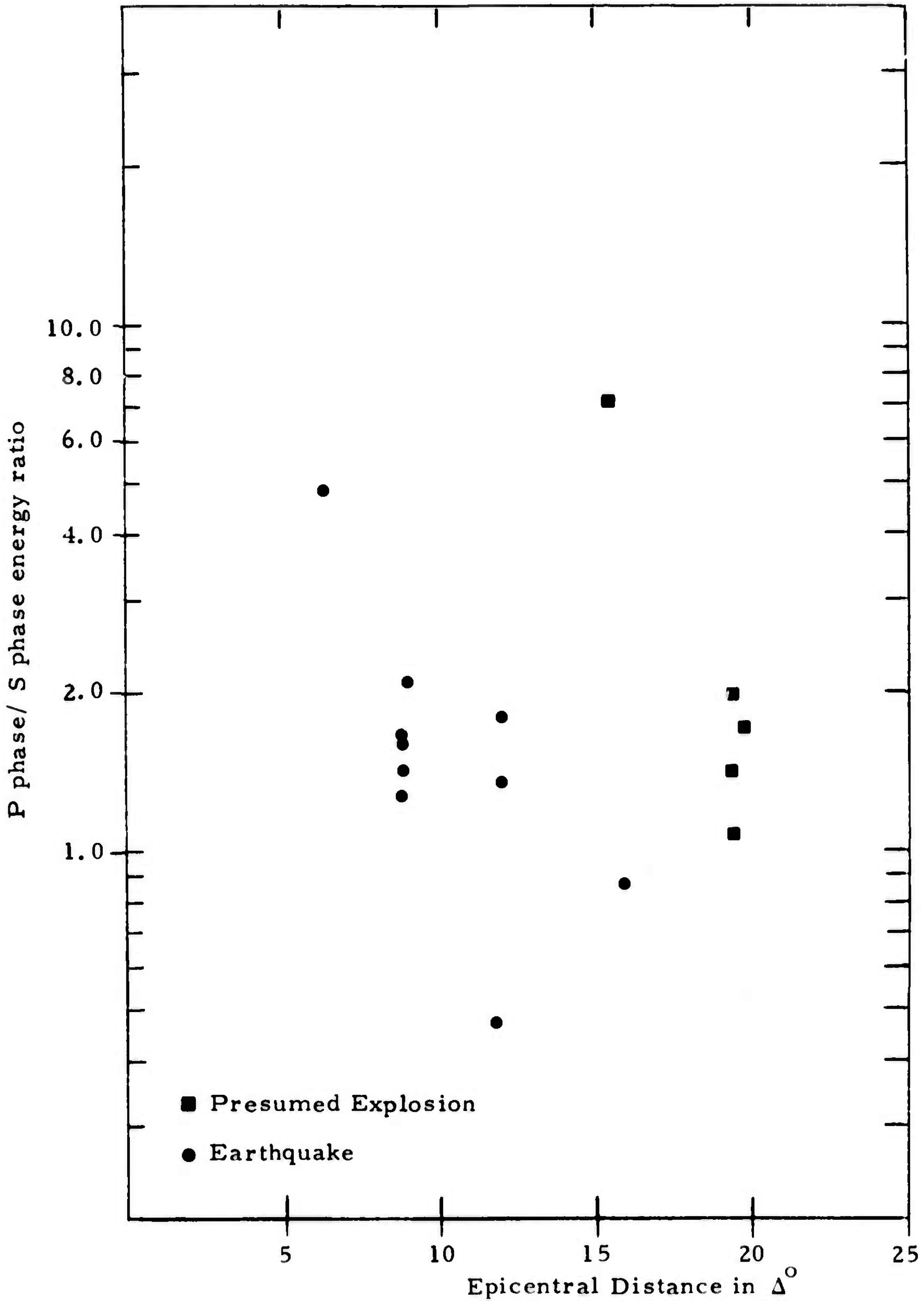

FIGURE III-7

P PHASE/S PHASE ENERGY RATIOS
FOR EVENT LESS THAN $20^{o}\Delta$

azimuth. High-quality travel-time information for the various phases as a clue to identifying the various geological provinces which may exist within regional distances and which may require consideration of P/S ratios on an azimuthal basis as well as distance.

c. Spectral Splitting

The spectral splitting discriminant is a ratio of the energy in two frequency bands of, for example, the P wave of an event. These bands are chosen to emphasize the relatively greater high-frequency energy in the P wave from an explosion as compared to an earthquake of equal magnitude.

This discriminant is applied on a routine basis at NORSAR for teleseismic events using these bands: 0.00 - 0.55 Hz, 0.55 - 1.50 Hz, and 1.50 - 5.00 Hz (Ringdal, 1973). These bands are not satisfactory for the first zone for two reasons: First, the lower end of the band used in this study, 0.90 Hz, used for noise rejection, eliminates the lowest band. Secondly, high frequency energy is less severely attenuated at short distances relative to the attenuation at teleseismic distances, so the 1.50 - 5.00 Hz band may be too broad for first zone use. The emphasis in this preliminary study was limited to determining the optimum frequency bands to use.

Figures III-3 and III-4 show the seismoprint output of the P wave for an earthquake WRS*166*12N (event 4) and a presumed explosion WES/262/11N (event 1), respectively. These two events are within one degree of one another and differ in magnitude by 0.1 m_b units on the single instrument (event 4 has an $m_b = 4.2$ and event 1 has an $m_b = 4.3$). A comparison of these two events shows the presumed explosion has a greater percentage of higher frequency energy than the earthquake.

From various theoretical source spectral considerations the explosions should have the greater high frequency energy content compared to the earthquakes of equivalent magnitudes. The magnitude estimates from the NORSAR beam and the NOAA-PDE bulletin are 1.3 m_b units apart. Since spectral ratios are expected to be a function of magnitude, these wide variations in magnitude estimates must be accounted for before spectral bands are selected for spectral ratio investigations.

d. Crustal and Upper Mantle Considerations

Regional amplitudes and travel-times are dependent upon the crust and upper mantle structure. Several regional crustal models are available for the NORSAR region (Pasechnik, 1970; Anderson, 1971; Belysevskii, 1973).

In this preliminary data set, two important observations concerning the character of the seismograms can be made. First, the absence of the Pg arrival (6.2 to 6.5 km/sec) at NORSAR is particularly puzzling since all the crustal models indicate a granitic layer of approximate Pg velocity. Secondly, the first arrival for event 16 (URA/299/05N) reported in the NORSAR bulletin from the array beam is not visible on the single instrument in spite of a good SNR for the remainder of the event. Both of these observations will have to be explained. This will require a wider range of distance, azimuth and magnitude events.

SECTION IV
CONCLUSIONS AND FUTURE PLANS

A. CONCLUSIONS

In general this investigation of regional events was hampered both by the classical seismic problem of inaccurate epicenter location and origin time, and by the larger estimates of m_b using first zone data rather than teleseismic data. Successful solutions to similar problems were developed in the first-zone studies of the western United States and the Nevada test site, but they were predicated upon having accurate travel time curves which presently don't exist for the NORSAR first-zone. The PDE epicenter information appears adequately accurate for most of the first-zone studies, but the same parameters from the NORSAR bulletin are not satisfactory. These relatively poorer location and origin time affect every portion of the analysis.

The small data base included here is sufficient to permit only a trial of the various measurements considered, but these results do define the problem areas. The lack of accurate travel-time curves prevents calibrating the magnitude measurements so that they are consistent with corresponding teleseismic estimates. Further, the lack of positive S wave and depth phase identification prevents any reliable estimation of depth.

The phase energy ratios appear to be effective discriminants even for such broad velocity windows used here. The addition of similar discriminants computed from long-period data should improve considerably their effectiveness.

The spectral splitting discriminant will require more data from earthquakes and explosions of similar magnitude before the most effective spectral bands can be determined and the effectiveness of this discriminant can be determined.

The absence of the P_g phase and the missing first arrival on one event indicate potential problem areas in the constructing of travel-time curves for the NORSAR first-zone area.

B. FUTURE PLANS

An event selection process has been set up so that in the future, data for these events can be ordered from NORSAR on a regular basis. A primary goal of the analysis will be to use events with accurate origin times and locations so that accurate travel-time curves can be constructed. Array beams will be formed using S wave velocities to improve the signal-to-noise ratio of the S wave and thus the reliability of their identification.

The development of travel-time curves for P, S, and possibly other phases for the NORSAR region will allow a reformulation of first-zone m_b measurements which conform to teleseismic estimates.

As a check on the accuracy of the first-zone travel-times and to permit the prediction of phases on the first-zone seismogram, a crustal model will be developed using the calculated travel-times and incorporating the various published crustal models into a unified crustal model of the NORSAR first-zone.

SECTION V
REFERENCES

Anderson, A. J., 1971, Deep Seismic Soundings in the Northern European Part of the USSR, in Vogel, A., editor, Deep Seismic Sounding in Northern Europe: Stockholm, The Swedish Natural Science Research Council (NFR).

Archambeau, C. B., E. A. Flinn, and D. G. Lambert, 1969, Fine Structure of the Upper Mantle, Journal of Geophysical Research, Vol. 74, No. 25.

Barnard, T. E., and R. L. Whitelaw, 1972, Preliminary Evaluation of the Norwegian Short-Period Array, Special Report No. 6, Extended Array Evaluation Program Contract Number F33657-71-C-0843, Texas Instruments Incorporated, Dallas, Texas.

Belysevskii, N. A., 1973, Geological Results of Deep Seismic Studies of the Earth's Crust, in papers presented at the Second All-Union Conference on the Study of the Earth's Crust and Upper Mantle by Methods of Explosion Seismology, L. F. Egonora, editor. Translated by Addis Translations International, Woodside California, UCRL-trans-10737.

Booker, A., and W. Mitronovas, 1964, An Application of Statistical Discrimination to Classify Seismic Events, Bulletin of the Seismological Society of America, Vol. 54, No. 3.

Carder, D. S., 1952, Local, Near-Regional, and Regional Earthquakes; Abstract, Bulletin of the Geological Society of America, Vol. 63, No. 12.

Cohen, T. J., 1969, Seismoprints, Geotech, A Teledyne Company, Seismic Data Laboratory Report No. 238.

Evernden, J. F., 1967, Magnitude Determination at Regional and Near-Regional Distances in the United States, Bulletin of the Seismological Society of America, Vol. 57, No. 4.

Eyres, J. S., P. R. Laun, and W. H. Swindell, 1972, Preliminary Evaluation of the Norwegian Long-Period Array, Special Report No. 5, Extended Array Evaluation Program Contract Number F33657-71-C-0843, Texas Instruments Incorporated, Dallas, Texas.

Herrin, E., (Chairman), 1968, 1968 Seismological Tables for P Phases, Bulletin of the Seismological Society of America, Vol. 58, No. 4.

Jeffreys, Sir Harold, and K. E. Bullen, 1940, Seismological Tables, Brit. Assn. Gray-Milne Trust.

Pasechnik, I. P., 1970, Characteristics of Seismic Waves from Nuclear Explosions and Earthquakes, Geosciences Bulletin, Series A. Vol. 1.

Ringdal, F., 1973, Evaluation of the Discrimination Capability of the Norwegian Seismic Array, Special Report No. 13, Texas Instruments Report Number ALEX(01)-STR-73-13, Contract Number F33657-72-C-0725.

Ringdal, F., and R. L. Whitelaw, 1973, Final Evaluation of the Norwegian Short-Period Array, Special Report No. 11, Texas Instruments Report Number ALEX(01)-STR-73-11, Contract Number F33657-72-C-0725.